

Global Ocean Evaporation Increases Since 1960 in Climate Reanalyses: How Accurate Are They?

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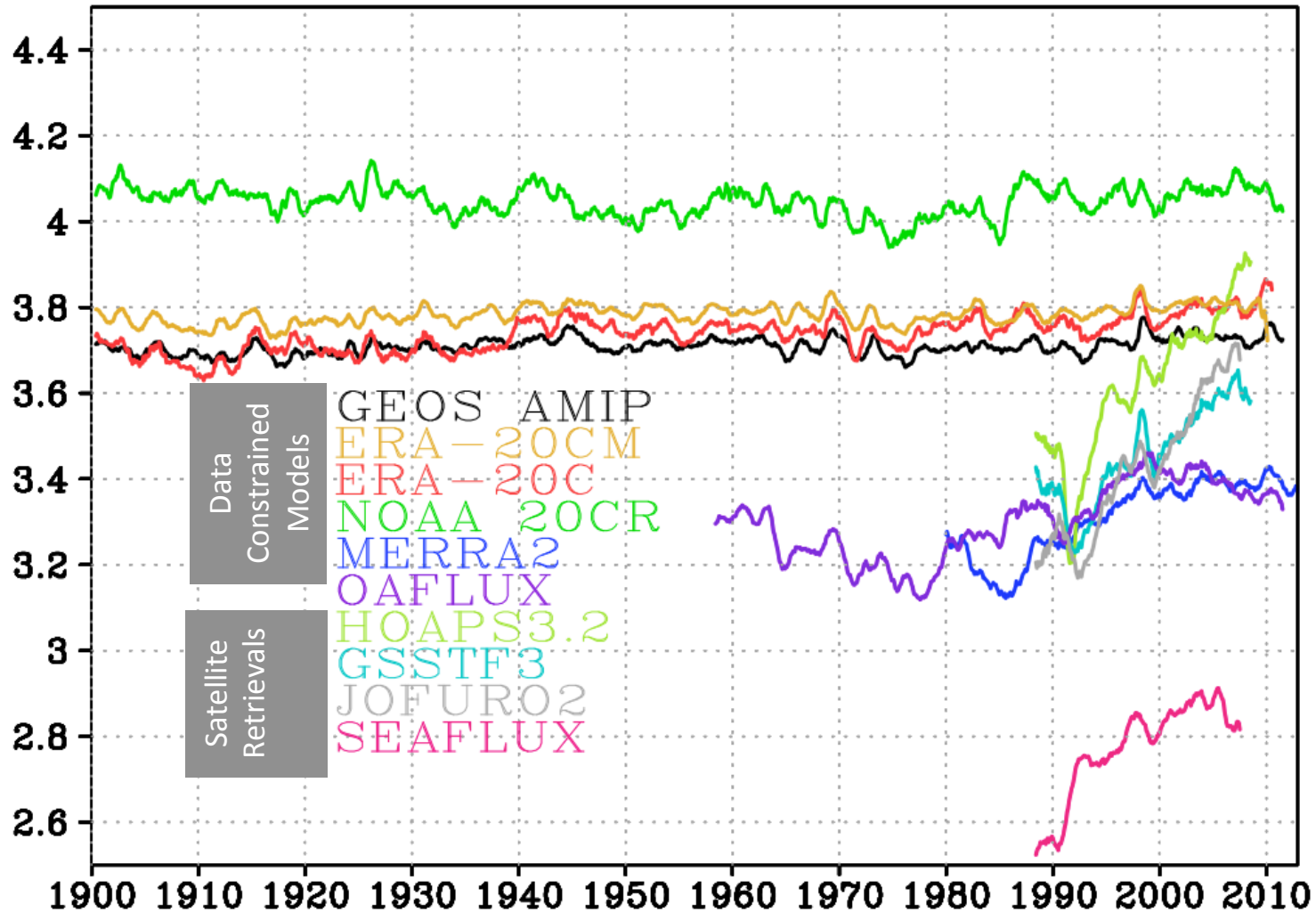
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Substantial Disparities Exist in Global Ocean Evaporation Estimates

Global Mean Evap 60N/S (mm/d) 12-mon smooth



A Hierarchy of Global Ocean LHF Estimates

← More Observations Constrained

AGCMs w/ Specified SSTs (AMIPs) GEOS-5, ERA-20CM Ensembles

Incorporate best historical estimates of SST, sea ice, radiative forcing
Atmospheric "weather noise" is inconsistent with specified SST. Instantaneous Sfc fluxes can be wrong sign (e.g. Indian Ocean Monsoon, high latitude oceans).
Averaging over ensemble members helps isolate SST-forced signal.

Reduced Observational Reanalyses: NOAA 20CR V2C, ERA-20C, JRA-55C

Incorporate observed Sfc Press (20CR), Marine Winds (ERA-20C) and rawinsondes (JRA-55C) to recover much of true synoptic or weather w/o shock of new sat obs.

Comprehensive Reanalyses (MERRA-2)

Full suite of observational constraints- both conventional and remote sensing.
But... substantial uncertainties owing to evolving satellite observing system.

Multi-source Statistically Blended OAFlux, LargeYeager

Blend reanalysis, satellite, and ocean buoy information. While climatological biases are removed, non-physical trends or variations in components remain.

"Observations"

Satellite Retrievals GSSTF3, SeaFlux, HOAPS3...

Global coverage. Retrieved near sfc wind speed, & humidity used with SST to drive accurate bulk aerodynamic flux estimates. Satellite inter-calibration, spacecraft pointing variations crucial. Short record (late 1987-present).

In situ Measurements ICOADS, IVAD, Res Cruises

VOS and buoys offer direct measurements. Sparse data coverage (esp south of 30S. Changes in measurement techniques (e.g. shipboard anemometer height).

Questions we'll address

- To what extent do Reduced Observations Reanalyses (RedObs) using sfc pressure (and wind) provide a realistic picture of multi-decadal evaporation variability?
- What is the range of estimates for evaporation sensitivity to SST change and can we understand these differences w / in the bulk aerodynamic framework?
- What processes govern both trends and signals of interannual variability (e.g. ENSO)?
- Possible accuracy assessment.

A Taylor Series Expansion of Bulk Aerodynamic Evaporation Around Monthly Climatology

As in Richter and Xie (2008), Lorenz et al (2010) we write the bulk formula for evaporation as a function of SST, Relative Humidity, Wind Speed, and Stability:

$$E = C_E \rho_a U q_o \left[q_s(SST) - RH \cdot q_s(SST + S) \right] \quad \text{near-sfc } q_a(T_{air})$$

where

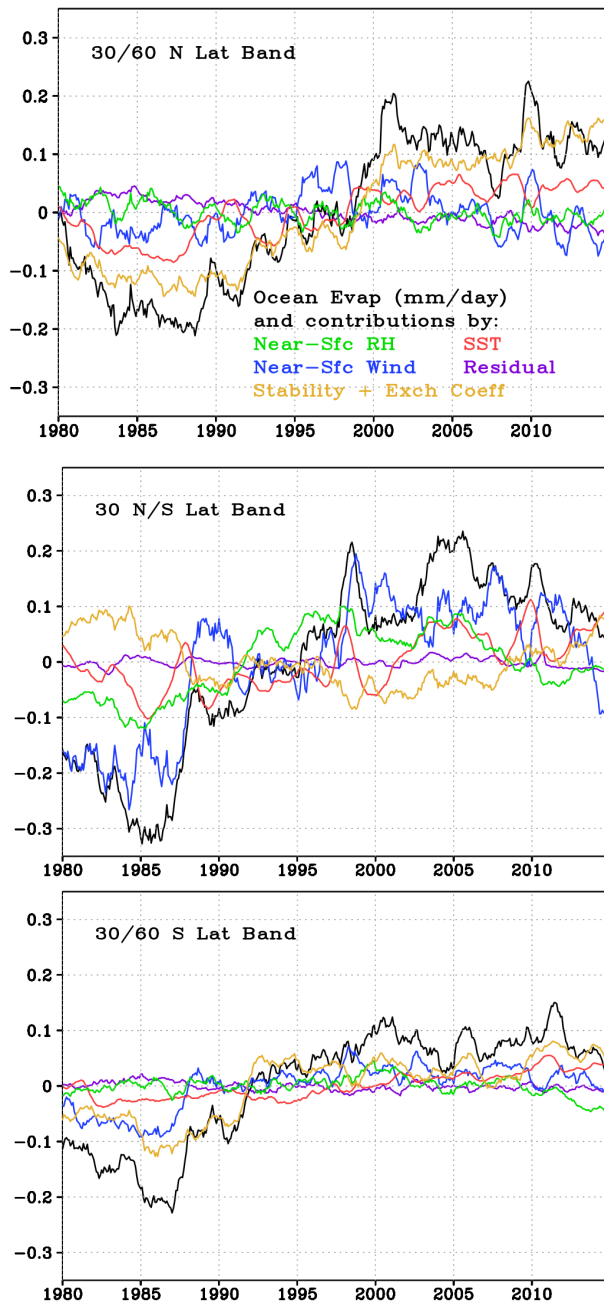
$$S = T_{air} - SST$$

By using an analytical (fitted exponential) expression for saturation specific humidity, a 1st Order Taylor series expansion for evaporation anomalies, δE , is

$$\delta E = \frac{\partial E}{\partial SST} \delta SST + \frac{\partial E}{\partial U} \delta U + \frac{\partial E}{\partial RH} \delta RH + \frac{\partial E}{\partial S} \delta S + \frac{\partial E}{\partial C_E} \delta C_E + res$$

where the partial derivatives are “sensitivities” built from monthly resolved climatology and $\delta()$ denotes a monthly anomaly. The first term involving SST changes only can be thought of as atmospheric forcing by SST and is equivalent to the Clausius-Clapeyron rate ($\sim 6\%$ per deg SST change over the globe).

Data Assimilation Challenges with Evolving Satellite Observing Systems

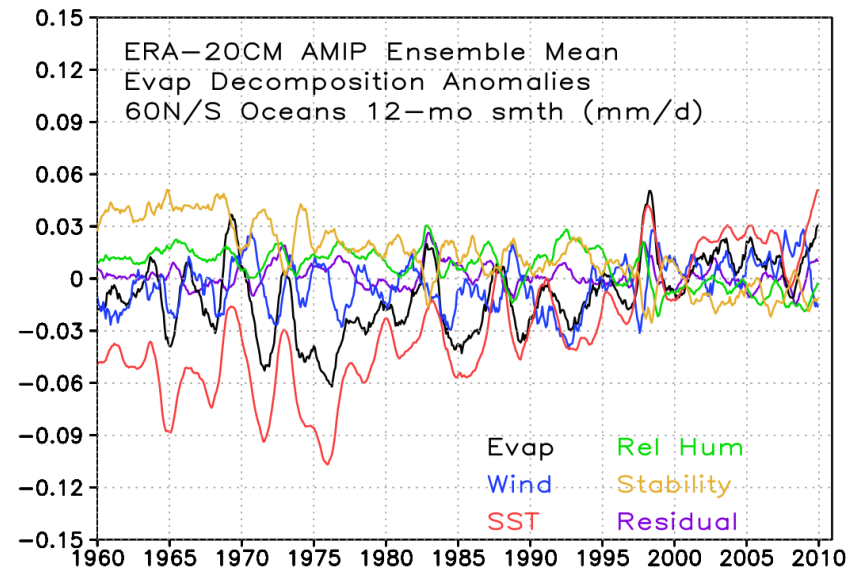
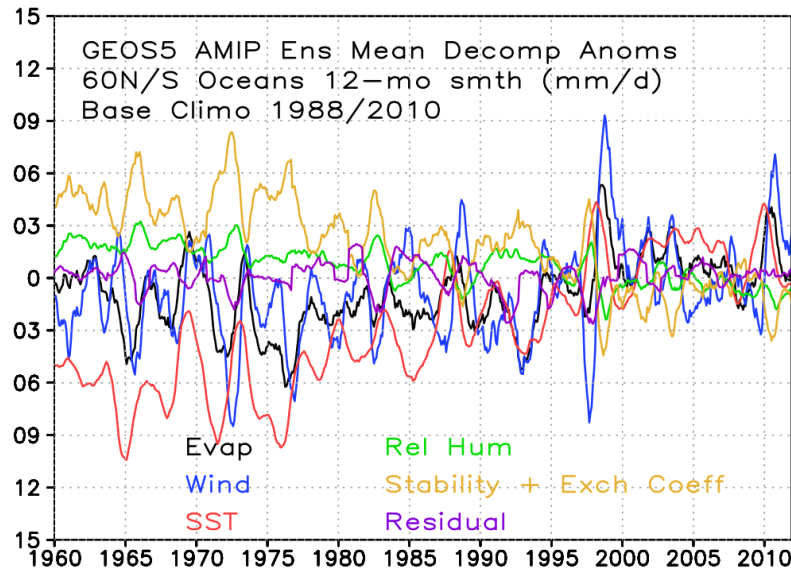


- Decomposition of the MERRA-2 ocean surface evaporation into contributing **components of SST (red), wind (blue), stability (yellow) and specific humidity (green)**. Units are mm day^{-1} . 12 month smoothing has been applied.
- SSM/I wind availability strongly affects Tropics and So. Hem.
- Assimilated temperature data affects extratropics stability contribution. Uncertainty is assimilated $T > \delta sst$?
- Convective stabilization controls in tropics affect stability and relative humidity but moisture & temperature assimilation

Evaporation Change Mechanisms (AMIP Ensembles)

Ocean 60 N/S time series (mm/d)

12 mon smoothing



1960 / 2010 Trends (% Climo Evap / Deg Global SST Change)

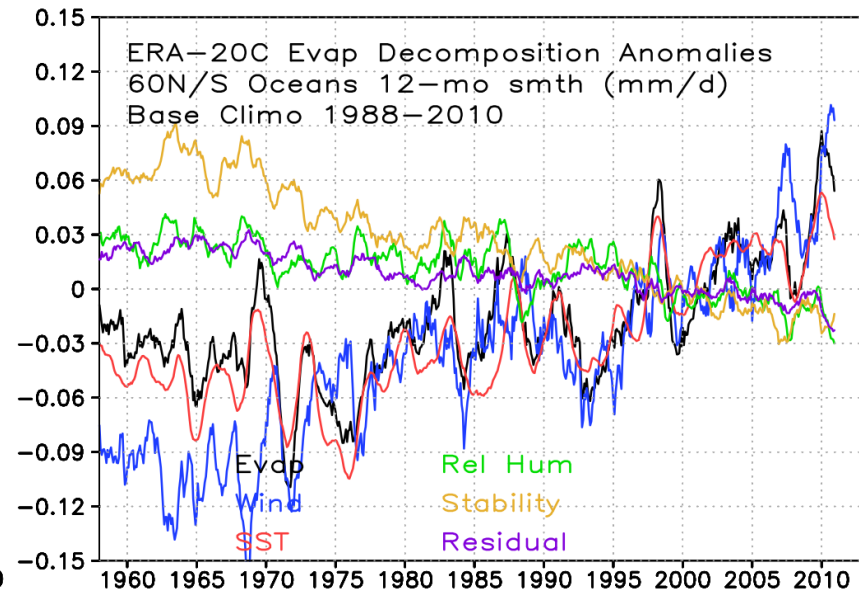
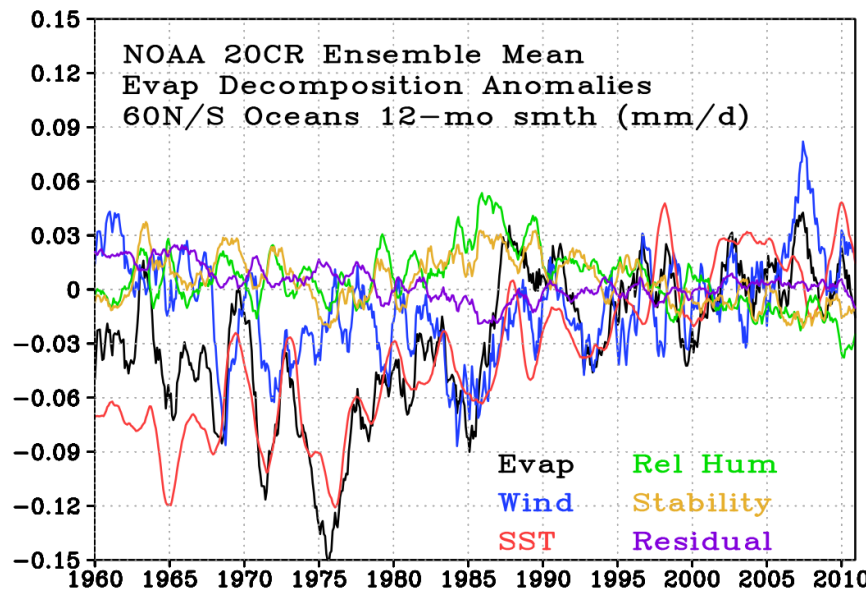
	Evap	SST	RH + Stab	Wind	Residual
GEOS-5	1.8	6.2	-4.4	1.6	-1.6
ERA-20CM	1.8	5.9	-4.3	-0.60	0.8

- Actual evaporation trend lies substantially below C-C Rate due to offsetting contributions from increased RH, Stability and residual (Exch Coeff).
- Wind-related trends are small (but interannual signals are large).

Evaporation Change Mechanisms (Reduced Obs Assimilation)

Ocean 60 N/S time series (mm/d)

12 mon smoothing



1960 / 2010 Trends (% of Climo Evap / Deg Global SST Change)

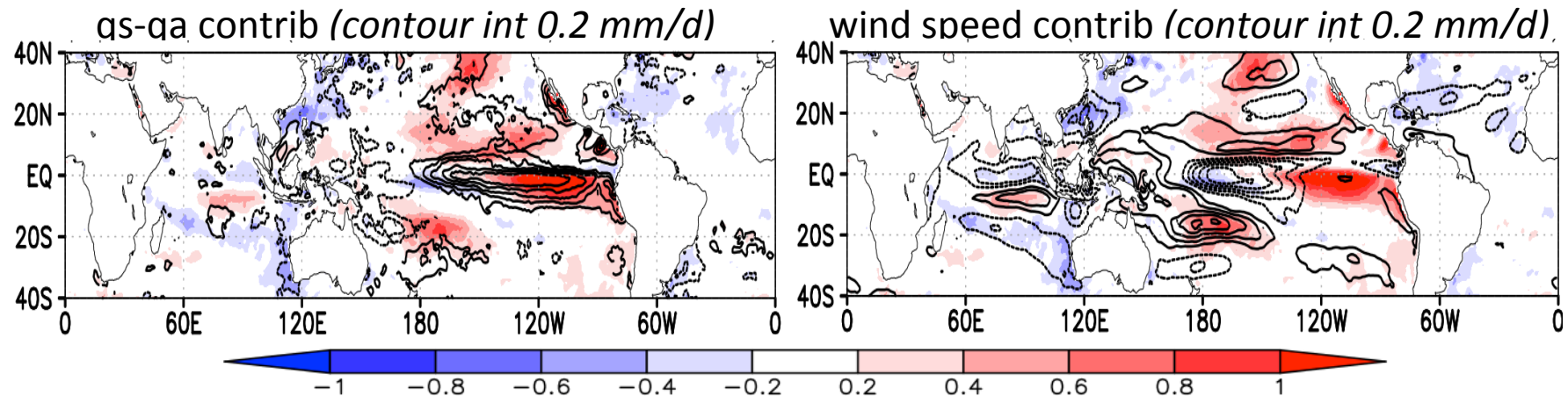
	Evap	SST	RH + Stab	Wind	Residual
NOAA 20CR	5.9	6.4	-0.6	1.0	-0.9
ERA-20C	4.6	5.9	-7.5	8.5	-2.30

- Both NOAA 20CR and ERA-20C have more decadal variability than AMIPs
- ERA-20C wind trend drives 20th Century evaporation trend exceeding C-C rate.

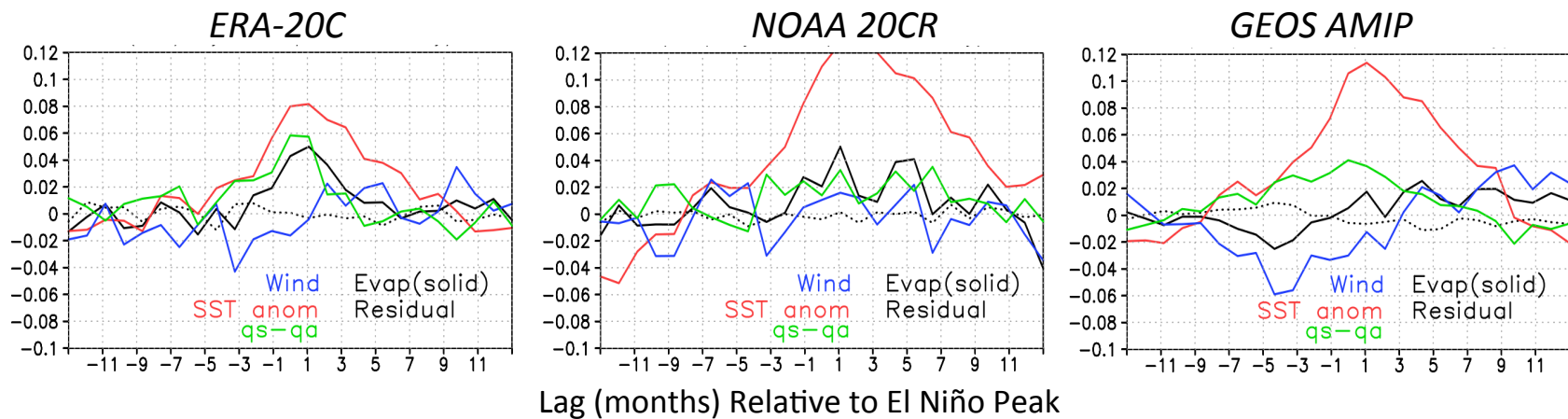
So What About The Strong Interannual Signals?

ERA-20C Composite

El Niño Evaporation Anomalies (shaded, mm/d)



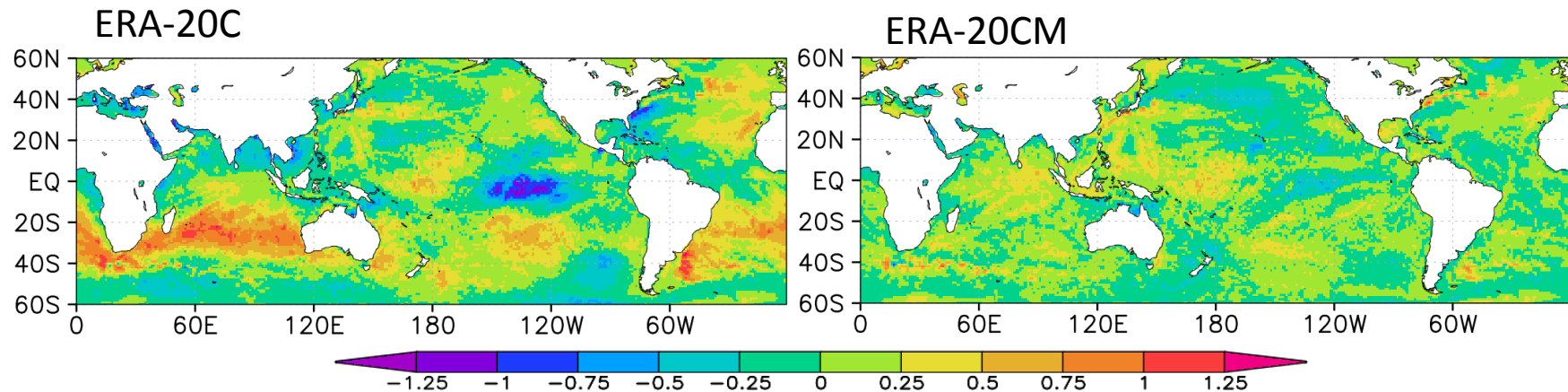
Global Ocean (60 N/S) Evap and WSPD, qs-qa Contributions (mm/day)
Composites of 1.0 σ events 1950/2010



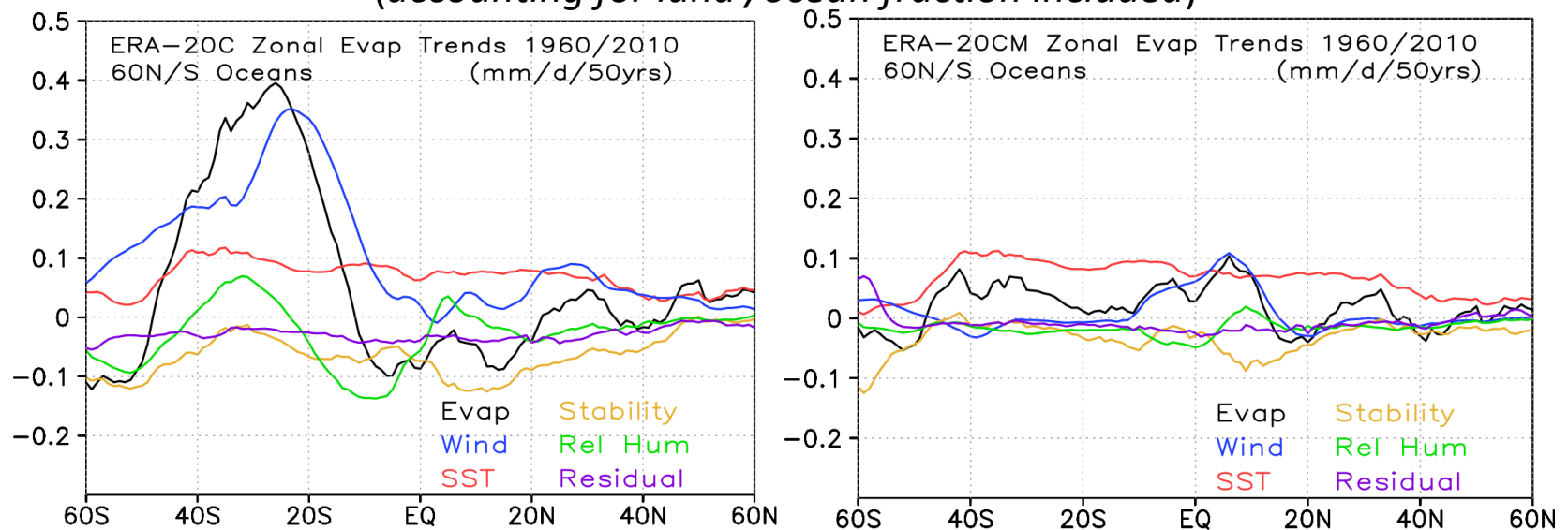
What is the Source of Large Evap Trends and
Can we Assess Their Validity?

Evaporation Trends 1960 / 2010:

The Effect of Sfc Press and Wind Obs over SST Forcing Alone

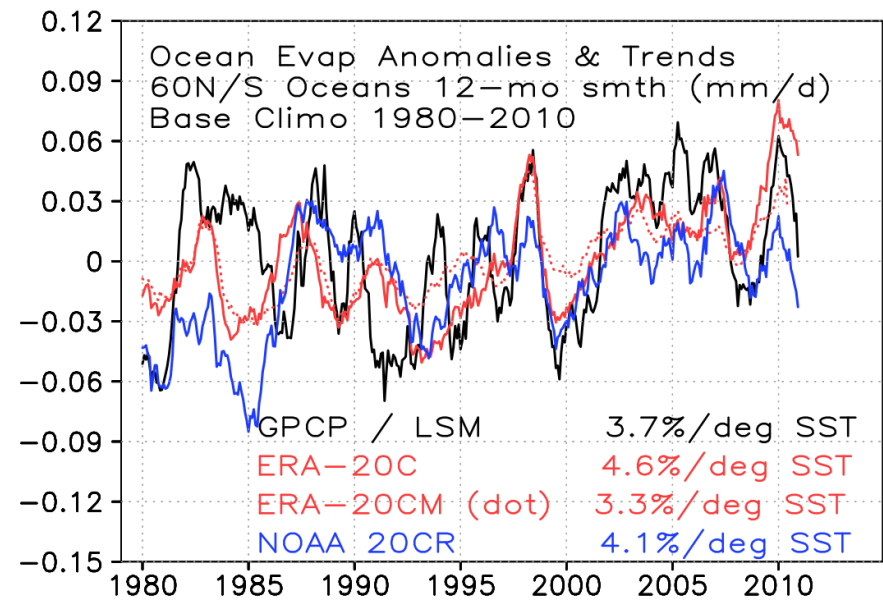
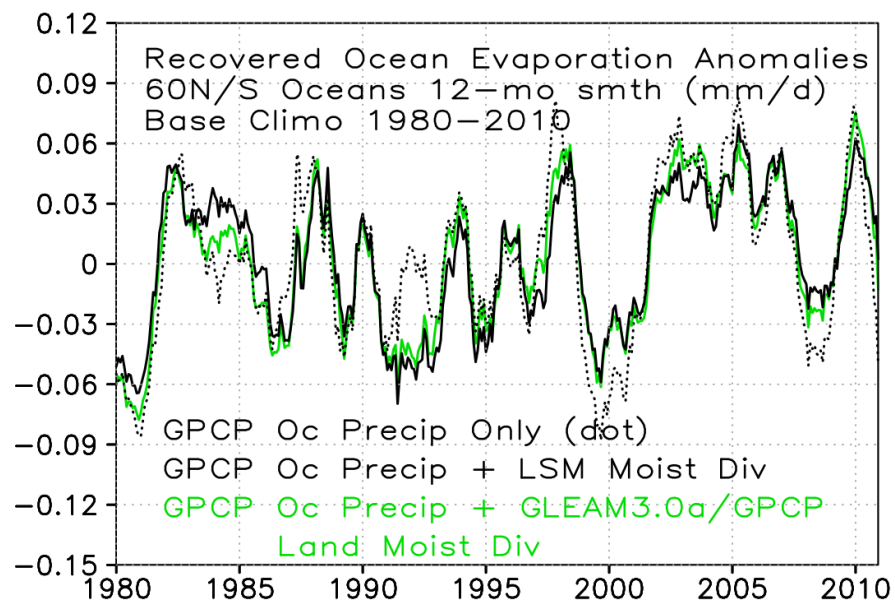


Zonal trends as function of latitude
(accounting for land /ocean fraction included)



Evaporation Consistency Check Using An Alternative Global Ocean Mean Calculation

- $E'_{OC} = P'_{OC} + \int_{area} (P - ET)'_{LAND} \delta a$. Changes in ocean evaporation anomalies are balanced by precipitation changes and transports to / from land. (Atmospheric storage is small on the scales of interest.)
- Use GPCP v2.3 precipitation (ocean, land) and $(P-ET)'$ from observationally constrained land surface models LSMs (*Robertson et al. 2016; GLEAM 3.0a ET, Martens et al. [2016, GMDD]*).
- Must account for land / ocean fractional coverage.



Summary Points:

- Consistent with coupled model results (e.g. Richter and Xie, 2008; Lorenz et al, 2010), ensemble specified SST (AMIP) experiments exhibit thermodynamic damping by RH and stability act to keep evaporation trends below C-C rate.
- Reduced Observations Reanalyses (RedObs) assimilating surface pressure (and wind) modify the SST-forced solution and appear to provide a more consistent picture of evaporation variability. Significant issues: uncorrected assimilated wind speed trends ; dearth of So. Hem. Obs.
- El Nino-related IA evap variations are large regionally. Equatorial wind speed decreases lead $q_s - q_a$ maximum → evap max tends to lag Eq SST max → coherent global signals.

Challenges:

- Cross-comparisons among “hierarchy” products with varied data input are useful in ferreting out uncertainties. Validation requires comparison to other water & energy balance components from varied sources.
- Significant changes in data availability in the Satellite Era continue to challenge comprehensive reanalyses. Continued data scrubbing / refurbishment and analysis of reanalysis model analysis increments is needed to understand data / physics bias interplay.
- Future versions of satellite evaporation retrievals will need better sensor calibration effects on wind speeds & Q_s - q_a . Weather “regime” approaches are a way forward.

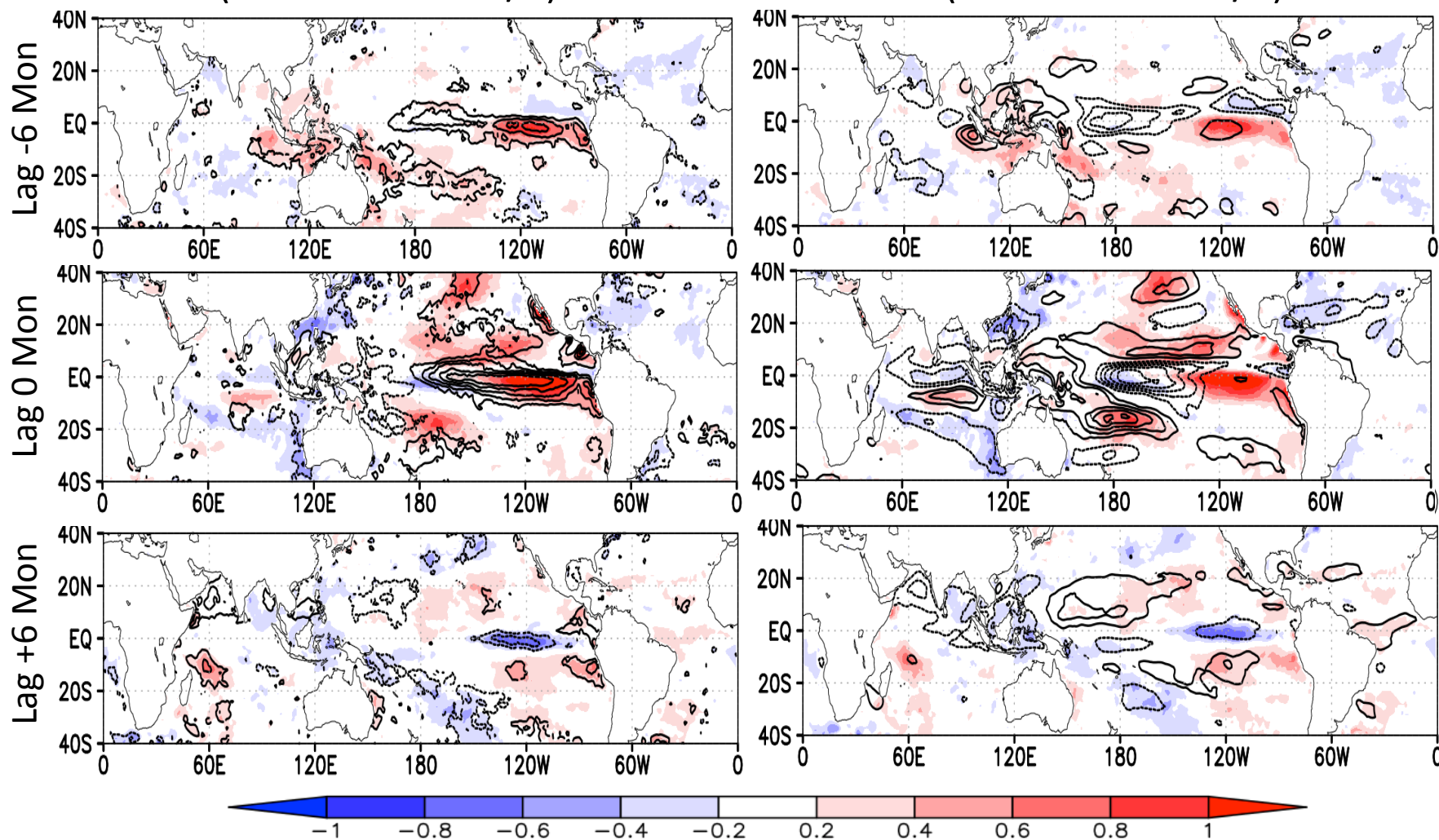
BACKUPS

ERA-20C

El Niño Evaporation Anomalies (shaded, mm/d)

qs-qa contribution contoured
(interval 0.2 mm/d)

wind speed contribution contoured
(interval 0.2 mm/d)



Inter-decadal Pacific Oscillation In ERA-20C

- Consistent pattern of evaporation changes (shaded) relate to SST gradient patterns and altered low-level circulation.
- Twin anticyclonic high pressure anomalies (green contours) develop in the eastern extra-tropical Pacific resulting from westward diabatic heating shift.
- Off-equatorial wind speeds Eq to 20 N/S (black contours) consistent with surface pressure gradient changes enhance evaporation.

